Chapter 7
Processes to Further Reduce Pathogens (PFRPs)

7.1 Introduction

Processes to Further Reduce Pathogens (PFRPs) are listed in Appendix B of the Part 503. There are seven PFRPs: composting, heat drying, heat treatment, thermophilic aerobic digestion, beta ray irradiation, gamma ray irradiation, and pasteurization. When these processes are operated under the conditions specified in Appendix B, pathogenic bacteria, enteric viruses, and viable helminth ova are reduced to below detectable levels. The PFRPs listed in Part 503 are essentially identical to the PFRPs listed under the 40 CFR Part 257 regulation, except that all requirements related solely to reduction of vector attraction have been removed.

This chapter provides detailed descriptions of the seven PFRPs listed in Part 503. Because the purpose of these processes is to produce Class A biosolids, the pathogen reduction process must be conducted concurrent to or prior to the vector attraction reduction process (see Section 4.2).

Under Part 503.32(a)(7), sewage sludge treated in these processes is considered to be Class A with respect to helminth ova, enteric viruses, and pathogenic bacteria. In addition, Class A biosolids must be monitored for fecal coliform or *Salmonella* sp. bacteria at the time of use on disposal, at the time the biosolids are prepared for sale or give away in a bag or other container for land application, or at the time the biosolids are prepared to meet the requirements for "exceptional quality" sludge (see Chapter 2) in 503.10(b), 503.10(c), 503.10(e), or 503.10(f) to ensure that growth of bacteria has not occurred (see Section 4.3). Guidelines regarding the frequency of pathogen sampling and sampling protocols are included in Chapter 9.

7.2 Composting

Composting is the controlled, aerobic decomposition of organic matter which produces a humus-like material. Sewage sludge which is to be composted is generally mixed with a bulking agent such as wood chips which increases porosity in the sewage sludge, allowing air to more easily pass through the composting material and maintain aerobic conditions. There are three commonly used methods of composting: windrow, static aerated pile, and within-vessel.

To be considered a PFRP under Part 503, the composting operation must meet certain operating conditions:

- Using either the within-vessel composting method or the static aerated pile composting method, the temperature of the sewage sludge is maintained at 55°C (131°F) or higher for 3 consecutive days.
- Using the windrow composting method, the temperature of the sewage sludge is maintained at 55°C (131°F) or higher for 15 consecutive days or longer. During the period when the compost is maintained at 55°C (131°F) or higher, there shall be a minimum of five turnings of the windrow.

For aerated static pile and in-vessel composting processes, temperatures should be taken at multiple points at a range of depths throughout the composting medium. Points which are likely to be slightly cooler than the center of the pile, such as the toes of piles, also should be monitored. Because the entire mass of sewage sludge must attain the required temperatures for the required duration, the temperature profiles from every monitoring point, not just the average of the points, should reflect PFRP conditions.

It has been found that points within 0.3 m (1 foot) of the surface of aerated static piles may be unable to reach PFRP temperatures, and for this reason, it is recommended that a 0.3 m (1 foot) or greater layer of insulating material be placed over all surfaces of the pile. Finished compost is often used for insulation. It must be noted that because the insulation will most likely be mixed into the composted material during post-processing or curing, compost used as an insulation material must be a Class A material so as not to reintroduce pathogens into the composting sewage sludge.

For windrow composting, the operational requirements are based on the same time-temperature relationship as aerated static pile and in-vessel composting. The material in the core of the windrow attains at least 55°C and must remain at that temperature for 3 consecutive days. Windrow turning moves new material from the surface of the windrow into the core so that this material may also undergo pathogen reduction. After five turnings, all material in the windrow must have spent 3 days at the core of the pile. The time-temperature regime takes place over a period of at least 15 consecutive days during which time the temperature in the core of the windrow is at least 55°C. See Appendix J for additional guidance.

Pathogen reduction is a function of three parameters:

- Ensuring that all sewage sludge is mixed into the core of the pile at some point during active composting
- Ensuring that all sewage sludge particles spend 3 consecutive days in the core during which time the temperatures are at 55°C
- Preventing growth of pathogenic bacteria in composted material

The first issue, ensuring that all material is mixed into the core of the pile, depends on the configuration of the windrows and the turning methodology. Pile size and shape as well as material characteristics determine how much of the pile is in the "hot zone" at any given time. Additional turning and maintenance of temperatures after the mandated 15 days are recommended, depending on the windrow configuration. For example, the Los Angeles County Sanitation District found that as many as 12-15 turnings were necessary to reduce pathogens in windrow composted sewage sludge (Personal Communication, Ross Caballero, Los Angeles County Sanitation District, 1998).

Second, it is important that once that material is in the pile core it be subject to the full time-temperature regime necessary to reduce pathogens. Therefore, the turning schedule and the recovery of the core zone to 55°C are important factors. If pile turning is not evenly distributed throughout the 15-day period, some material may not spend adequate time in the core of the pile. Additionally, pile temperatures generally drop off immediately after turning; if temperatures in the pile core do not quickly recover to 55°C (within 24 hours), the necessary pathogen reduction period of 3 days will not be achieved.

Because of the operational variability, pathogen reduction in windrow composting has been found to be less predictable than pathogen reduction in aerated static pile or in-vessel composting. In order to improve pathogen reduction, the following operational guidelines are recommended.

- Windrow turning should take place after the pile core has met pathogen reduction temperatures for 3 consecutive days. Windrow turnings should be evenly spaced within the 15 days so that all material remains in the core zone for 3 consecutive days; allowing additional time as needed for the core temperature to come up to 55°C.
- Pathogen reduction temperatures (55°C) must be met for 15 consecutive days at the pile core.
- Temperatures should be taken at approximately the same time each day in order to demonstrate that 55°C has been reached in the pile core within 24 hours after pile turning.
- Testing frequency should be increased; a large sewage sludge windrow composting operation recommends testing each windrow for *Salmonella* sp. before piles are distributed (Personal Communication, Ross Caballero, Los Angeles County Sanitation District, 1998). Samples are taken after turning is completed, and piles which do not comply with Class A requirements are retained on site for further composting.

Vector Attraction Reduction (VAR)

The options for demonstrating vector attraction reduction for both PFRP and PSRP composting are the same. Option 5 is the most appropriate for composting operations. This option requires aerobic treatment (e.g. composting) of the sewage sludge for at least 14 consecutive days at over 40°C (104°F) with an average temperature of over 45°C (113°F). This is usually easily attained by sewage sludge composting.

The PFRP and VAR requirements can be met concurrently in composting. For within-vessel or aerated static pile composting, the temperature profile should show PFRP temperatures at each of the temperature monitoring points for 3 consecutive days, followed by a minimum of 11 more days during which time the average temperature of the pile complies with VAR requirements. For windrow piles, the compliance with PFRP temperatures will also fulfill VAR requirements.

PFRP temperatures should be met before or at the same time that VAR requirements are fulfilled in order to reduce the potential for pathogen regrowth. However, continued curing of the composting material will most likely further prevent the growth of pathogenic bacteria from taking place.

Like all microbiological processes, composting can only take place with sufficient moisture (45-60%). Excessive aeration of composting piles or arid ambient condition may dry composting piles to the point at which microbial activity slows or stops. The cessation of microbial activity results in lowered pile temperatures which can easily be mistaken for the end-point of composting. Although composting may appear to have ended, and compost may even meet vector attraction reduction via Option 7, overly dried compost can cause both odor problems and vector attraction if moisture is reintroduced into the material and microbial activity resumes. It is therefore recommended that the composting process be maintained at moisture levels between 45-60% (40-55% total solids) (Epstein, 1997).

Microbiological Requirements

If the conditions specified by the Part 503 regulation are met, all pathogenic viruses, bacteria, and parasites will be reduced to below detectable levels. However, it may be difficult to meet the Class A microbiological requirement for fecal coliforms even when *Salmonella* sp. bacteria are not present. Biological sewage sludge treatment processes involving high temperatures, such as composting, can reduce *Salmonella* sp. to below detectable levels while leaving some surviving fecal coliforms. If sufficient nutrients remain in the sewage sludge, bacteria can later grow to significant numbers. It may be preferable, therefore, to test composted sewage sludge directly for *Salmonella* sp., rather than using fecal coliforms as an indicator of pathogen control.

Although not mandated by the Part 503 regulation, compost is usually maintained on site for longer than the required PFRP and VAR duration. In order to produce a high-quality, marketable product, it has been found that a curing period, or the period during which the volatile solids in the sewage sludge continue to decompose, odor potential decreases, and temperatures decrease into the mesophilic (40-45°C) range, is necessary. Depending on the feedstock and the particular process, the curing period may last an additional 30 - 50 days after regulatory requirements are met.

In general, compost is not considered marketable until the piles are no longer self-heating. It is important to note that compost piles that are cooled by excessive aeration or that do not self-heat because the material is too dry to support microbial activity may not actually be fully decomposed.

It has been found that further reduction of organic material takes place during the curing phase of composting (Epstein, 1997). Therefore microbiological testing should take place at the end of the curing process when compost is prepared for sale or distribution. Compost which is stored on site for extended periods of time until it can be sold or distributed must be tested for compliance with microbiological limits when it is to be used or disposed.

7.3 Heat Drying

Heat drying is used to reduce both pathogens and the water content of sewage sludge. The Part 503 PFRP description of heat drying is:

- Sewage sludge is dried by direct or indirect contact with hot gases to reduce the moisture content to 10% or lower. Either the temperature of the sewage sludge particles exceeds 80°C (176°F) or the wet bulb temperature of the gas in contact with the sewage sludge as it leaves the dryer exceeds 80°C (176°F).

Properly conducted heat drying will reduce pathogenic viruses, bacteria, and helminth ova to below detectable levels. Four processes are commonly used for heat drying sewage sludge: flash dryers, spray dryers, rotary dryers, and steam dryers. Flash dryers used to be the most common heat drying process installed at treatment works, but current practice favors rotary dryers. These processes are briefly described below. More detailed descriptions are provided in EPA's Process Design Manual (EPA, 1979).

Flash Dryers

Flash dryers pulverize sewage sludge in the presence of hot gases. The process is based on exposing fine sewage sludge particles to turbulent hot gases long enough to attain at least 90% solids content.

Spray Dryers

A spray dryer typically uses centrifugal force to atomize liquid sewage sludge into a spray that is directed into a drying chamber. The drying chamber contains hot gases that rapidly dry the sewage sludge mist. Some spray drying systems use a nozzle to atomize sewage sludge.

Rotary Dryers

Rotary dryers function as horizontal cylindrical kilns. The drum rotates and may have plows or louvers that mechanically mix the sewage sludge as the drum turns. There are many different rotary kiln designs, utilizing either direct heating or indirect heating systems. Direct heating designs maintain contact between the sewage sludge and the hot gases. Indirect heating separates the two with steel shells.

Steam Dryers

Indirect steam dryers utilize steam to heat the surface of the dryers which will come into contact with the sewage sludge. The heat transfer surface may consist of discs or paddles, which rotate to increase their contact with the sewage sludge.

Vector Attraction Reduction

No further processing is required because the PFRP requirements for heat drying also meet the requirements of Option 8 for vector attraction reduction (the percent solids must be at least 90% before mixing the sewage sludge with other materials). This fulfills the requirement of Option 7 if the sewage sludge being dried contains no unstabilized solids.

Drying of sewage sludge to 90% solids deters the attraction of vectors, however, unstabilized dried biosolids which are rewet may become odorous and attract vectors. Therefore, it is recommended that materials be used or disposed while the level of solids remains high and that dried material be stored and maintained under dry conditions.

Some operators have found that maintaining stored material at solids levels above 95% helps to deter reheating because microbiological activity is halted. However, storage of materials approaching 90% total solids can lead to spontaneous combustion with subsequent fires and risk of explosion. While there is little likelihood of an explosion occurring with storage of materials like pellets, precautionary measures such as maintaining proper oxygen levels and minimizing dust levels in storage silos and monitoring temperatures in material can reduce the risk of fires.

Microbiological Requirements

Heat dried biosolids must be tested for fecal coliform or *Salmonella* sp. at the last point before being used or disposed. For example, biosolids should be tested immediately before they are bagged or before they leave the site for bulk distribution. If material is stored for a long period of time, it should be re-tested, even if previous testing has shown the biosolids to have met the Part 503 regulation. This is particularly important if material has been rewetted.

7.4 Heat Treatment

Heat treatment processes are used to disinfect sewage sludge and reduce pathogens to below detectable levels. The processes involve heating sewage sludge under pressure for a short period of time. The sewage sludge becomes sterilized and bacterial slime layers are solubilized, making it easier to dewater the remaining sewage sludge solids. The Part 503 PFRP description for heat treatment is:

- Liquid sewage sludge is heated to a temperature of 180°C (356°F) or higher for 30 minutes.

Two processes have principally been used for heat treating sludge in preparation for dewatering: the Porteous and the Zimpro process. In the Porteous process the sewage sludge is preheated and then injected into a reactor vessel. Steam is also injected into the vessel under pressure. The sewage sludge is retained in the vessel for approximately 30 minutes after which it is discharged to a decant tank. The resulting sewage sludge can generally be concentrated and dewatered to high solids concentrations. Further dewatering may be desirable to facilitate sewage sludge handling.

The Zimpro process is similar to the Porteous process. However, air is injected into the sewage sludge before it enters the reactor and the vessel is then heated by steam to reach the required temperature. Temperatures and pressures are approximately the same for the two processes.

Vector Attraction Reduction

Heat treatment in most cases must be followed by vector attraction reduction. Vector attraction reduction Options 6 to 11 (pH adjustment, heat drying, or injection, incorporation, or daily cover) may be used (see Chapter 8). Options 1 through 5 would not typically be applicable to heat treated sludge unless the sludge was digested or otherwise stabilized during or after heat treatment (e.g. through the use of wet air oxidation during heat treatment).

Microbiological Requirements

When operated according to the Part 503 requirements, the process effectively reduces pathogenic viruses, bacteria, and viable helminth ova to below detectable levels. Sewage sludge must be properly stored after processing because organic matter has not been reduced, and therefore, growth of bacteria can occur.

Heat treated sewage sludge must be tested for fecal coliform or *Salmonella* sp. at the time of use or disposal or as it is prepared for sale or distribution. If heat treated biosolids are subsequently composted or otherwise treated, pathogen testing should take place after that processing is complete.

7.5 Thermophilic Aerobic Digestion

Thermophilic aerobic digestion is a refinement of the conventional aerobic digestion processes discussed in Section 6.2. In this process, feed sewage sludge is generally pre-thickened and an efficient aerator is used. In some modifications, oxygen is used instead of air. Because there is less sewage sludge volume and less air to carry away heat, the heat released from biological oxidation warms the sewage sludge in the digester to as high as 60°C (140°F).

Because of the increased temperatures, this process achieves higher rates of organic solids reduction than are achieved by conventional aerobic digestion which operates at ambient air temperature. The biodegradable volatile solids content of the sewage sludge can be reduced by up to 70% in a relatively short time. The digested sewage sludge is effectively pasteurized due to the high temperatures. Pathogenic viruses, bacteria, viable helminth ova and other parasites are reduced to below detectable limits if the process is carried out at temperatures exceeding 55°C (131°F).

This process can either be accomplished using auxiliary heating of the digestion tanks or through special designs that allow the energy naturally released by the microbial digestion process to heat the sewage sludge. The Part 503 PFRP description of thermophilic aerobic digestion is:

- Liquid sewage sludge is agitated with air or oxygen to maintain aerobic conditions and the mean cell residence time of the sewage sludge is 10 consecutive days at 55°C to 60°C (131°F to 140°F).

The thermophilic process requires significantly lower residence times (i.e., solids retention time) than conventional aerobic processes designed to qualify as a PSRP, which must operate 40 to 60 days at 20°C to 15°C (68°F to 59°F), respectively. Residence time is normally determined by dividing the volume of sewage sludge in the vessel by the volumetric flow rate. Facility operation should minimize the potential for bypassing by withdrawing treated sewage sludge before feeding, and feeding no more than once a day.

In the years following the publication of the Part 503 regulation, advances in thermophilic digestion have been made. It should be noted, however, that complete-mix reactors with continuous feeding may not be adequate to meet Class A pathogen reduction because of the potential for bypassing or short-circuiting of untreated sewage sludge.

Vector Attraction Reduction

Vector attraction reduction must be demonstrated. Although all options, except Options 2, 4, and 12 are possible, Options 1 and 3 which involve the demonstration of volatile solids loss are the most suitable. (Option 2 is appropriate only for anaerobically digested sludge, and Option 4 is not possible because it is not yet known how to translate SOUR measurements obtained at high temperatures to 20°C [68°F].)

Thermophilically aerobically digested biosolids must be tested for fecal coliform or *Salmonella* sp. at the time of use or disposal or as it is prepared for sale or distribution. If digested biosolids are subsequently composted or otherwise treated, pathogen testing for either fecal coliform or *Salmonella* sp. should take place after processing is complete.

7.6 Beta Ray and Gamma Ray Radiation

Radiation can be used to disinfect sewage sludge. Radiation destroys certain organisms by altering the colloidal nature of the cell contents (protoplasm). Gamma rays and beta rays are the two potential energy sources for use in sewage sludge disinfection. Gamma rays are high-energy photons produced by certain radioactive elements. Beta rays are electrons accelerated in velocity by electrical potentials in the vicinity of 1 millions volts. Both types of radiation destroy pathogens that they penetrate if the doses are adequate. The Part 503 PFRP descriptions for irradiation systems are:

Beta Ray Irradiation

- Sewage sludge is irradiated with beta rays from an accelerator at dosages of at least 1.0 megarad at room temperature (ca. 20°C [68°F]).

Gamma Ray Irradiation

- Sewage sludge is irradiated with gamma rays from certain isotopes, such as Cobalt 60 and Cesium 137 [at dosages of at least 1.0 megarad] at room temperature (ca. 20°C [68°F]).

The effectiveness of beta radiation in reducing pathogens depends on the radiation dose, which is measured in rads. A dose of 1 megarad or more will reduce pathogenic viruses, bacteria, and helminths to below detectable levels. Lower doses may successfully reduce bacteria and helminth ova but not viruses. Since organic matter has not been destroyed with processing, sewage sludge must be properly stored after processing to prevent contamination.

Although the two types of radiation function similarly to inactivate pathogens, there are important differences. Gamma rays can penetrate substantial thicknesses of sewage sludge and can therefore be introduced to sewage sludge by either piping liquid sewage sludge into a vessel that surrounds the radiation source (Figure 7-1) or by carrying composted or dried sewage sludge by hopper conveyor to the radiation source. Beta rays have limited penetration ability and therefore are introduced by passing a thin layer of sewage sludge under the radiation source (Figure 7-2).

Vector Attraction Reduction

Radiation treatment must be followed by vector attraction reduction. The appropriate options for demonstrating vector attraction reduction are the same as for heat treatment (see Section 7.4), namely Options 6 to 11. Options 1-5 are not applicable unless the sewage sludge is subsequently digested.

Microbiological Requirements

Irradiated sewage sludge must be tested for fecal coliform or *Salmonella* sp. at the time of use or disposal or as it is prepared for sale or distribution.

7.7 Pasteurization

Pasteurization involves heating sewage sludge to above a predetermined temperature for a minimum time period. For pasteurization, the Part 503 PFRP description is:

- The temperature of the sewage sludge is maintained at 70°C (158°F) or higher for 30 minutes or longer.

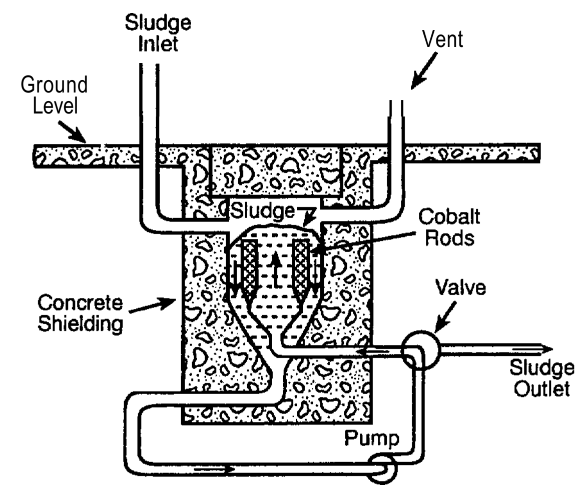

Figure 7-1. Schematic representation of cobalt-60 (gamma ray) irradiation facility at Geiselbullach, Germany. Source: EPA. 1979.

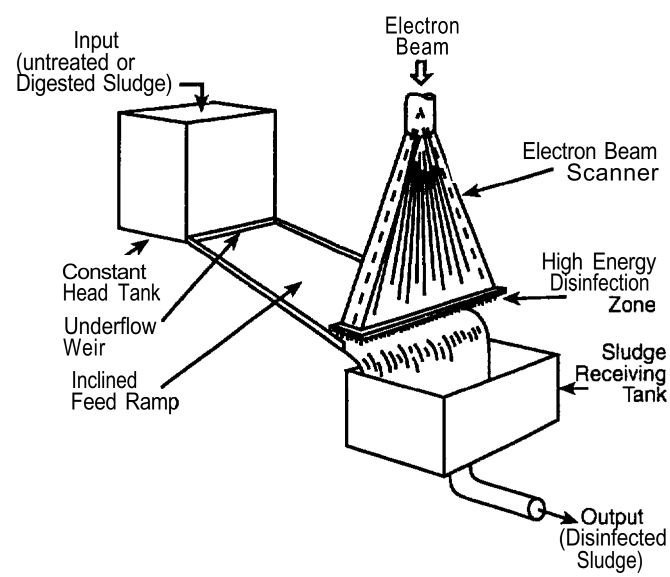

Figure 7-2. Beta ray scanner and sludge spreader. Source: EPA,1979.

Pasteurization reduces bacteria, enteric viruses, and viable helminth ova to below detectable values. Sewage sludge can be heated by heat exchangers or by steam injection. Although sewage sludge pasteurization is uncommon in the United States, it is widely used in Europe. The steam injection method is preferred because it is more effective at maintaining even temperatures throughout the sewage sludge batch being processed. Sewage sludge is pasteurized in batches to prevent recontamination that might occur in a continuous process. Sewage sludge must be properly stored after processing because the organic matter has not been stabilized and therefore odors and growth of pathogenic bacteria can occur if sewage sludge is re-inoculated.

In theory, quicklime can be used to meet the requirements for pasteurization of sewage sludge. The water in the sludge slakes the lime, forming calcium hydroxide, and generates heat. However, it is difficult to ensure that the entire mass of sewage sludge comes into contact with the lime and achieves the required 70°C for 30 minutes. This is particularly true for dewatered sewage sludges. Processes must be designed to 1) maximize contact between the lime and the sewage sludge, 2) ensure that adequate moisture is present, 3) ensure that heat loss is minimal, and 4) if necessary, provide an auxiliary heat source. Pasteurization cannot be accomplished in open piles.

In addition, in order for pasteurization to be conducted properly, facility operators must be trained with regard to 1) the proper steps to be taken to ensure complete hydration of the alkaline reagent used, 2) the evaluation of the slaking rate of the lime-based alkaline material required for their particular process, specifying the reactivity rate required, 3) the proper measurement of pH, 4) an awareness of the effect of ammonia gassing off and how this affects the lime dose, and 5) the necessity for maintaining sufficient moisture in the sewage sludge/alkaline mixture during the mixing process to ensure the complete hydration of the quicklime and migration of hydroxyl ions throughout the sewage sludge mass. This is to ensure that the entire sewage sludge mass is disinfected.

EPA-sponsored studies showed that pasteurization of liquid sewage sludge at 70°C (158°F) for 30 minutes inactivates parasite ova and cysts and reduces the population of measurable viruses and pathogenic bacteria to below detectable levels (U.S. EPA, 1979). This process is based on the pasteurization of milk which must be heated to at least 63°C (145°F) for at least 30 minutes.

Vector Attraction Reduction

Pasteurization must be followed by a vector attraction reduction process unless the vector attraction reduction conditions of Option 6 (pH adjustment) have been met. The options appropriate for demonstrating vector attraction reduction are the same as those for heat treatment (see Section 10.4), namely Options 6 to 11. Options 1 to 5 are not applicable unless the sludge is subsequently digested.

Microbiological Requirements

Pasteurized sludge must be tested for fecal coliform or *Salmonella* sp. at the time of use or disposal or as it is prepared for sale or distribution. In Europe, serious problems with regrowth of *Salmonella* sp. have occurred, so pasteurization is rarely used now as a terminal treatment process. Pre-pasteurization followed by mesophilic digestion has replaced the use of pasteurization after digestion in many European communities.

7.8 Equivalent Processes

Under Class A Alternative 6, sewage sludge treated in processes that are determined to be equivalent to PFRP are considered to be Class A with respect to pathogens (assuming the treated sewage sludges also meet the Class A microbiological requirement). Table 11-2 in Chapter 11 lists some of the processes that were found, based on the recommendation of EPA's Pathogen Equivalency Committee, to be equivalent to PFRP under Part 257. Chapter 11 discusses how the PEC makes a recommendation of equivalency.

References and Additional Resources

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